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ABSTRACT

The confusion concerning the meaning of the terms science and technology is readily apparent in the literature of various study groups concerned with the issue of technological literacy, including researchers working in the fields of mathematics, engineering, and education. The literature would suggest that rather than one relationship between science and technology, there are many. These fields are mutually exclusive and not mutually dependent, although each has been enhanced by contributions of the other. Generally, if the scope of a problem is clearly defined as solving a human or social problem within a specified environment, then the activity is technological. If, on the other hand, the goal of the problem does not restrict the scope of the results sought or the direction of inquiry, then, in most cases, the activity is scientific. Practitioners designing technological literacy programs would do better to avoid the seemingly unresolvable controversy over the difference between science and technology and concentrate instead on determining what constitutes the science of technology. It is proposed that technology be viewed as a science that deals with the creation, utilization, and behavior of adaptive systems in relation to human beings, society, and the environment. (MN)

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Science and Technology:
An Analysis of Meaning

It would seem that one should be able to make the assumption that there is general agreement on the meaning and use of the words science and technology. Unfortunately this is not true. In fact, there is mass confusion, not only within the fields commonly identified as science and technology but also in the minds of legislators, academics and other people responsible for a wide range of affairs concerning science and technology.

The fact there is so much confusion as to the use and meaning of the terms and the fact their meanings are central to issues of public policy ranging from establishing programs to enhance the technological literacy of the general citizenry to determining the expenditure of research funds, suggest that the first task is to concentrate on describing the nature of the problem. The second task is to explore the problem as it affects a primary interest throughout the country today, namely, technological literacy. The latter problem will illustrate the need to pursue the task of differentiating the terms science and technology.

Finally, an attempt will be made to provide a direction and a possible solution to the problem facing those responsible for designing, implementing, developing and evaluating programs of study for the enhancement of technological literacy.

Nature of the problem

The confusion concerning science and technology is readily apparent in the literature of various study groups, particularly when they attempt to deal with technology. Often the descriptor science and technology is used in the first paragraph of the proposal or committee report. This indicates a recognition of two distinct entities related by a coordinating conjunction. However, almost immediately the word technology is dropped and the rest of the report focuses on a lengthy discussion of science, generally in the restricted sense of physics and chemistry with an occasional statement or reference to the biological sciences. If there is discussion of technological literacy there is generally reference to the discipline of mathematics.

An example of the problem can be illustrated by referring to the widely quoted report of the National Science Board Commission on Precollege Education in Mathematics, Science and Technology--"Educating Americans for the 21st Century: A Plan of Action for improving mathematics, science and technology education for all American elementary and secondary students so that their achievement is the best in the world by 1985."

The opening paragraph on page 27 exposes in two sentences the problem.

The Commission on Precollege Education in Mathematics, Science and Technology was established by the National Science Board and the Director of the National Science Foundation in April 1982. It was charged with the development of a national action plan to improve the effectiveness of mathematics and science education in the public schools. (p. 27)

Note the inclusion of the word technology in the title of the commission and the omission of the word in the charge to the commission.

Similar problems of omission and confusion exist in other literature including journal articles. For instance, one finds confusion among the engineering profession in the use of the word. A typical example is an article written by Edward A. Friedman in Engineering Education in 1980. The intriguing title was: "Technology as an Academic Discipline." Friedman found that the typical dictionary definition of the word technology was inadequate so he wrote his own.

Technology refers to systems and artifacts incorporating knowledge of the physical and social worlds which affect society's activities and organizations. (p. 211)

A reasonable and interesting definition. But then he states: "Technology is a broadly encompassing realm that includes disciplines such as applied science and engineering." To further confuse the issue he states: "Engineering, in turn, encompasses the subdomain of 'engineering technology'" (p. 211). The confusion is brought about by confusing the realm of academic disciplines with vocations such as engineering and engineering technology.

Later Friedman proposes that it is important to identify technology as an independent realm, separate from science as a category of thought and human endeavor. The reason for this proposal is his observation that "too often discussions go astray because distinctions between science and technology are not properly perceived" (p. 211).

One has to agree with his observation. Most people assume they know what science is and that knowledge of science is essential for technological advancement, a myth that has no basis in fact. Yet, it is perpetuated by many who claim to be scientists but, contrary to their training in objectivity, ignore the evidence.

To illustrate the seriousness of the problem observe the following perception of the relation of science and technology in the National Science Board Commission report.

Since technology is a set of tools* for students to use, it is important that all students have a positive experience with technology throughout their school years, from grade K through 12. (p. 69)

The report goes on to state that "while mathematics and science classrooms are the traditional homes of technology,* an understanding of technology can be achieved in other subject disciplines as well" (p. 69). This perception of technology permeates the entire report.

*italics added by author

One wonders where the writers of the report were educated and whether they are even aware of Part Seven, Technology, in the Encyclopedia Britanica. This section delineates the field of technology and clearly separates it from the confusion so evident in the literature.

Scientific and Technological Literacy

In the March 30, 1984 issue of Science, Richard C. Atkinson, chancellor of the University of California at San Diego and former director of the National Science Foundation noted that the conclusions of several reports, including the Commission on Excellence in Education, the Education Commission of the States and the Carnegie Foundation for the Advancement of Teaching each concluded, as did the National Science Board's Coleman report, that technological literacy needs to be a part of general literacy. The Coleman report stressed that technological literacy is quite different from scientific literacy and mathematical literacy. It was noted that "an understanding of scientific and mathematical concepts doesn't automatically result in an understanding of technology." However, in the very next sentence the report states: "Technology is a product* of mathematics, science and engineering." Later the report states that "technology consists of tools, devices and techniques that have been created to implement* ideas born of science and engineering" (p. 73).

*italics added by author

These and a host of other reports illustrate the considerable interest in the issue of technological literacy as well as the confusion on what technology is. One such report is from the Wingspread Conference held in June of 1982. David Saxon, in the Wingspread report, called the technological literacy issue a major problem, even a national scandal (p. 5). He speculated that the renewed interest in scientific and technological literacy stems from the fact that "our society is becoming increasingly and irreversibly technological, and because scientific investigation is increasingly and irreversibly concerned with almost unimaginable extremes of space and time, which removes it even further from the realm of daily experience" (p. 7).

In the United States and elsewhere there is great concern among educators and others about science education, technology education, scientific literacy and technological literacy. Yet, as brief visits to the literature illustrate, there is considerable confusion as to what is meant by scientific and technological literacy.

There are no agreements as to definitions and certainly confusion about relationships. Some authorities believe science, engineering and technology are related but distinct enterprises while others believe all are part of the broad enterprise of science in some way with mathematics an important component of each.

If the problem is to be engaged and possibly solved, some effort must be directed toward defining and/or describing the fields of science and technology so criteria can be developed to differentiate between them. This is a necessary first step if our public policy debates are to provide any semblance of reasonable solutions. It is also a necessary first step if those in education are to navigate with a clearer vision while attempting to meet their responsibilities in designing and developing appropriate education programs. In addition, it seems necessary to enhance and focus the dialogue concerning science and technology so more appropriate research agendas related to issues surrounding scientific and technological literacy can be established. Our current intellectual confusion does not serve any legitimate purpose.

Science and Technology-- Relationships and Differentiations

Perspective--a view from the literature

The primary reason for the interest in determining the differences and relationships is because of the impact of technological change on people and society, and the belief that citizens in a democratic society should be technologically and scientifically literate. Those who make decisions about the future--elected representatives, corporate managers, and people in general--are concerned about impacts of science and technical means on society and individuals.

Most writers conclude that there are differences between technology and science. And most writers, to a greater or lesser degree, attempt to show relationships with few definitive conclusions. This stems from at least two factors: the background, experience, and value context of the writer; and the changing nature of both technology and science. Many writers discuss differences or relationships based on seventeenth- or eighteenth-century technology and science, and then project their findings to the twentieth century. Also, there seems to exist, among those who write about the issues, a decided proscience perspective. Some hold that technological advance comes from the practical application of scientific discovery. They prepare elaborate lineage studies to show that certain scientific events occurred before certain technological events, therefore establishing that science precedes technology.

Other investigators have shown that the linkages between events in technology and science are not proved. In fact, according to Lynn White, "until the middle of the nineteenth century there were remarkably few connections between science and technology" (p. 161). White maintains that, if anything, technology had a greater influence on science than science on technology.

The attempt to build a case by looking backward and placing a higher order of value on contemplation than on

action has delayed the probability of gaining true insight into the nature of the differences, relationships or new structures.

When exploring the relationship between technology and science, many individuals restrict technology to invention or the application of a scientific theory or law to a specific technical device. By doing so, they restrict not only the true meaning of technology but that of science as well. The belief that technology is the translation of scientific knowledge into practical form is held most often by individuals outside the fields of technology and science.

A more accurate relationship is presented by people like I. I. Rabi, a noted scientist who was also involved in the development of many technical devices utilized extensively by today's world. One of his contributions was the development of microwave and radar devices. Professor Rabi, in reflecting on the technology-science relationship, questions whether science has been so important in the development of much of the technical means available today. He noted that in earlier civilizations great technological progress was made without science; that there were developments in metals and metal working before the advent of chemistry or metallurgy, as well as development in textiles, building and construction, transportation, mining, agriculture, forestry, food preservation, and energy conversion and power development. Yet, the belief that

science creates new knowledge which technologists then apply is stated so often that it has been accepted as true.

This belief was so prevalent that the U.S. Department of Defense funded Project Hindsight to determine the contributions which made possible the development of twenty weapons systems. Seven hundred key events, critical to the development of the weapons systems, were studied to determine whether they were technological or scientific. The findings of the study were reported in November 1966. Over 99 percent of the events critical to the development of the weapons systems were technological events; only 0.3 percent of the events were found to result from basic science. The results were startling and contrary to commonly held views.

Another study, conducted by the Illinois Institute of Technology Research in 1968, Technology in Retrospect and Critical Events in Science, or TRACES (1968),* illustrated that a relationship between technology and science did exist but not in a direct linear form. What was discovered was that technological or mission-oriented research and development efforts brought about nonmission or basic science research which later influenced a given innovation (Layton, 1971).

*The TRACES project documented the events that were considered to be crucial in leading to five innovations; magnetic ferrites, videotape recorder, oral contraceptive pill, electron microscope, and matrix isolation.

Edwin Layton believes that the problem of discussing the technology-science relationship is the assumption that science and technology represent different functions performed by the same community. In reality, science and technology represent different communities, each with different goals, sets of values, social controls, and reward systems. The result is that science begets more science and technology more technology, which was also the finding of Project Hindsight.

Gibbons and Johnson found that science acts in a supporting rather than an initiating role (Jevons, p. 737). Their study showed that there is a relationship, but the importance of science to the development of technology has been exaggerated.

It seems as though much of the evidence to make the case of the importance of science to technology or the unity of technology and science has been overstated. It depends on what Melvin Kranzberg (1968, p. 27) describes as "chronological fallacy"; the belief that because one event preceded another chronologically, the events were connected causally. The most common connections, often prepared in chart form to show the relationships between prior science and later technology are the development of the steam engine and the transistor. The 1500-year period from Heron's experiments with expanding steam to James Watts' improvement of Newcomen's atmospheric steam engine and the

development of the transistor in the late 1940s are cited to illustrate the decreasing period of time from scientific discovery to technological development. The problem with these comparisons is that the development of the steam engine did not begin with Heron, but with Newcomen and his predecessors, and that the steam engine was a technological development, not a scientific one. The development of the steam engine came about because of a problem with mine drainage. Therefore, historians such as Kranzberg conclude that "new technology grows mostly out of old technology, not out of science," and "scientists concern themselves chiefly with the problem posed by science, not by technology."

J. M. Langrish and others also have questioned the chronology methodology (p. 35). They offer four reasons:

1. Difficulty in defining the scientific discovery on which a technological application is based. Different time intervals are assigned by different authors for given innovations.
2. Possible biases in selection of innovations and events due to absence of standard selection procedures. "It is in fact not difficult to produce sets of examples which show time lags increasing*substantially during the last hundred years or so."
3. Impossibility of observing anything other than a short time-lag for recent discoveries.

*italics added by author

"Discoveries made in the last few years may be exploited in the future, and such cases are of necessity excluded from consideration."

4. Many cases have negative time-lags. Many times technological advance comes before* the scientific advances that help to make them understandable such as was the case with the first synthetic rubber and plastics which were produced prior to the development of polymer chemistry.

we should not misread the evidence, however. There seems to be relationships, but of a different order than commonly believed. According to Kranzberg, the relationship between technology and science can best be described as a disunity rather than a unity, and as two distinct orders of activity engaged in by human beings with an ongoing dialectic between them (1968, p. 30). The relationship is more dependent on the situation or problem than on doctrine. It is a pragmatic relationship, free of formal protocol, and exists in specific contexts which vary according to the situation (1968, pp. 32-33). Rather than one relationship there are many, with the initial entree and dialectic determined by the situation and the problem.

Case after case can be cited illustrating the fallacy of the "science precedes technology" doctrine, even in fields

*italics added by author

such as chemical technology, aeronautics, and electricity. The attempt to link the production of sal ammoniac to scientific theories has not been proved (Schofield). The creation and development of the aeroplane by Orville and Wilbur Wright was not dependent on science but on the development of new technical means and the use of technological modes of thinking and doing. The difference between technology and science, whether in studying questions about sal ammoniac production or flight, is distinct, particularly with reference to the goals, the nature of the problem, and the problem setting.

Technology

Goal: to create the human capacity to do; to create new and useful products, devices, machines, or systems.

Problem: complex and interrelated problems involving design, materials, energy, information, and control. Many variables, both technical and social. Involves total system design.

Setting: situated directly in the social milieu.

Science

Goal: to obtain fundamental understanding of nature and the physical universe.

Problem: small, highly detailed, manageable problems designed to contribute to a body of information that may provide the base for generalizable theories.

Setting: isolated from requirement of meeting direct social needs.

Relationships--Contemporary

Most recent investigations conclude that technology and science are distinctly different forms of human endeavor. The concept of technology and science being different ends of the same continuum is probably false. What is more probable is that there are two distinct forms of activity

with different goals, questions and means, each contributing to the other through a noncompulsory dialectic. Both fields are mutually exclusive and not mutually dependent, although each field has been enhanced by contributions of the other.

Historically, technology and science have different antecedents. Technology has always been situated directly in the social milieu and conditioned by values, attitudes, and economic factors. The latter is evident in the research of Jacob Schmookler, an economist, who investigated whether (1) important inventions are typically induced by scientific discoveries, and whether (2) inventions are typically induced by intellectual stimuli provided by earlier inventions (pp. 57-58).

Schmookler and his colleagues compiled chronologies of important inventions in four industries: petroleum refining, paper making, railroading, and farming. Schmookler noted that although none of these industries owed its origin to scientific discoveries, the petroleum and paper making industries have had relationships with science similar to the electrical, plastic, nuclear, and electronic industries. Hence, he concluded, the hypothesis that scientific discoveries direct the course of invention, if true, would have a fair chance of surviving the test.

Two types of inventions were included in the study: inventions that were economically important in their effect

on the industry, and inventions that were technologically important in providing a base for subsequent innovations which were significant economically. Nine hundred and thirty-four inventions were identified using these criteria for the period 1800 to 1957; 235 of the inventions were in agriculture, 284 in petroleum refining, 185 in paper making, and 230 in railroading.

On analysis it was found that few, if any, of the inventions were directly stimulated by specific scientific discoveries, although each field had inventions which did depend on science. Decisions on whether to invent or to develop an invention for commercial use were not automatic; they were made on social and economic grounds. Similarly, it was determined that invention and technological development are not automatic outgrowths of discovery; rather, they depend on value judgments made in the "context of the times."

The investigators also established that scientific discovery is seldom a sufficient condition for invention, either in the short or the long run, and that particular scientific discoveries are seldom even necessary conditions for later inventions (Schmookler, pp. 70-71). It seems as though technological progress cannot be predicted from the progress of science even though science opens up a variety of alternative paths for invention and technological development. Choice of the path of development depends

largely on extrascientific factors. In general, Schmookler's study supports Schrier's contention that "not all technology is scientifically based, nor is all scientific research directly applicable to technology" (p. 345).

Any analysis of the relationship of technology and science must, therefore, be based on the fact that each has different attributes and that the definitions generally used to differentiate technology are inadequate and oftentimes superficial.

One way to differentiate between technology and science is to probe the historical antecedents of each discipline, the ideologies on which they are based, and the philosophical positions. This approach provides an essential insight into the problem of the technology-science relationship throughout history. Just as present societies perceive technology and science differently and create a new systematic social technology, so did past societies perceive technology and science differently. If a true perception of technology or science at a given time in history is to be attained, then it is necessary to structure the perspective from the ideologies and social contexts of that era, not the present. This is true because there has been a continual evolution in meaning of the words technology and science. In different cultures and at different periods in history, there were different meanings for the words, as there are today.

Another way is to examine the body of knowledge of each endeavor and compare the structure of the body of knowledge and the agreed-upon methods of adding new knowledge. What are the focuses of the problems, the nature of the problems, and in what social context do they exist? This is similar to a procedure suggested by Otto Mayr for differentiating between science and technology. Mayr suggests that discussions on differentiating science and technology be focused on several categories, namely,

- (1) the nature of the knowledge structure,
- (2) the type of work and activities engaged in by the people who do the work,
- (3) the motivation (ideologies) of the people who engage in technology or science, and
- (4) the aims and goals toward which the activities are directed.

Answers to these and other questions about how technology and science each address the past, present, or future will provide evidence that technology and science are two different endeavors.

So too would investigations of the goals and scope of inquiry of each discipline, critical variables for distinguishing between technology and science (Gruender, pp. 456-457).

The goals of the discipline concern the purposes of the activity while scope concerns the narrowness or breadth

of the activity. If the goal of an activity is set by some specific human problem, the nature of activity would be technical; whereas if the goal of the activity is based on curiosity and interest in finding basic generalizable theories, the activity would be scientific. Caution should be exercised in making too simplistic a separation. Abstract theories can be used for the solution of practical problems just as the solution of practical problems often leads to abstract theories.

Scope is generally established by the goal, aim, or purpose of the problem, inquiry, or activity. If the scope of the problem is clearly defined as solving a human or social problem within a specified environment, then the activity is technological. If, on the other hand, the goal of the problem, inquiry, or activity does not restrict the scope of the results sought or the direction of inquiry then in most cases the activity is scientific.

Technology is situated in a human and social context from which the goals which direct the activities of the discipline are derived and from which the scope of the field of inquiry is determined. In the process of development, the goals and scope of technology have been altered as new potential presented new choices. Today, rather than focusing on problems concerned with specific tools for a specific application in a given craft within a limited social environment, the goals and scope of technological problems include

inquiry into total systems and their interrelatedness, technically and socially. In this context the perception of our technical means changes, as does the reason for studying technology.

Science is different. It is essential in pure science that the human element be eliminated, that the variability of human responses be controlled (Ashby, p. 82). The goal of science is to seek explanation for the behavior of the natural world, not to solve problems related to creating adaptative means to aid humans to live in the natural world. Anna J. Harrison has proposed that science is the process of investigation* of physical, biological, behavioral, social, economic and political phenomena. Harrison uses process in a collective sense, encompassing everything the investigator does from the selection of the phenomena to be investigated to the assessment of the validity of the results. The outcome is scientific knowledge. Technology is perceived to be the process of production* and the delivery of goods and services and technological innovation is the process of investigating* how to produce and deliver more effectively goods or services, modify significantly their characteristics, or create and deliver new goods or services. The outcome is technological knowledge consisting of a data base, an array of methodologies, and an array of concepts (p. 1242).

*italics added by author

An alternative view--technology as a science

Individual perceptions of various topics or phenomena are largely dependent on a person's background, the amount of study and reflection given to the topic, and personal experiences with the phenomena. This is certainly true of science and more so in the case of technology. With respect to technology, viewpoints about its nature range all the way from technology as a tool to technology as a major component of the adaptive systems of civilization. It is thought of as skill, craftsmanship, artifacts, technique, work or a system of work, engineering, a body of knowledge, a discipline, a system of means, an effect and other similar constructs. Similar ranges of viewpoints exist with respect to science. Each viewpoint differs depending on the perception of the individual espousing that viewpoint.

The many and diverse viewpoints are of little help to those concerned with establishing public policy with respect to scientific and technological literacy. If there are no common agreements on meaning, it is not possible to develop curricula with the goal of scientific or technological literacy, nor is it possible to establish programs of assessment to determine levels of scientific and technological literacy among the population, if this is the goal.

If this is the goal then the basic questions become:
What is science? What is technology?

Most unabridged dictionaries define science as a branch of knowledge or study dealing with a body of facts or truths systematically determined or systematic knowledge of the physical or material world. There is general agreement that science means not one branch of knowledge but numerous branches of knowledge such as anthropology, biology, geology, physiology, psychology, sociology, and zoology, among others. The common ending shared by all the sciences listed, ology, means a science or any science or branch of knowledge.

If one were to be scientifically literate it would mean some level of literacy in the various sciences.

What would it mean to be technologically literate? If the question was approached from the many diverse viewpoints and definitions of technology reviewed previously, no common agreement as to the meaning of technological literacy is possible. However, if technology is defined as a science the same as biology, sociology and other ology denoting a branch of knowledge systematically determined, then technological literacy is one form of scientific literacy. This approach seems to provide some clarity and focus. To explore this approach further the next step would be to determine, as specifically as possible, the focus of this science called technology.

At this point a definition is in order as a means to provide a framework for further dialogue and discussion.

It is proposed that technology is:

the science that deals with the creation, utilization and behavior of adaptive systems including tools, machines, materials, techniques and technical means and the behavior of these elements and systems in relation to human beings, society and the environment.

Analyzing the definition, we find that a technologist might be involved in any number of activities ranging from creating technical devices, means or systems; to utilizing the technical means; to studying the behavior of various technological systems; to identifying the impact of various technical means on human beings, society and the environment.

Similarly this implies that a technologically literate person would have knowledge about and understanding of the primary elements stated in the definition. Those desiring to create programs of study for the purpose of attaining technological literacy would design programs that contained the essential elements implied in the definition. Briefly, these essential elements would consist of, but not be limited to, the following categories of knowing and doing.

1. The history, evolution, nature and development of technical means including knowledge of the people, places and cultures where the means were invented and developed.
2. Knowledge and understanding of the processes of invention and innovation including experience in the process.

3. Knowledge and understanding of the behavior of adaptive systems and subsystems such as communication, production and transportation including the tools, machines, materials, techniques and technical means used in these systems.
4. Knowledge and understanding of the behavior of various technical elements and adaptive systems and the assessment of the impact of these elements and systems in relation to human beings, society and the environment.

If we approach the problem of technological and scientific literacy from the perspective proposed in most literature concerning science and technology, there does not seem to be any way of reaching a valid and agreed-upon approach.

In the alternative approach proposed, science is not a single entity. There are many sciences. Further, technology is really one of the sciences when viewed as a branch of knowledge or a field of study that has been determined systematically.

Therefore, technology is not science; it is one of the sciences. And Science is not one entity but a term used to denote those human activities that are associated with branches or knowledge or study that have been systematically determined.

Thus, the question is not to differentiate between science and technology but to determine just what is the science of technology that has been systematically determined. This, it seems, is a much more valid approach to the various problems facing those responsible for the derivation of public policy about technology.

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